

ISSN 1392-3196

Žemdirbystė=Agriculture, vol. 97, No. 3 (2010), p. 105–116

UDK 631.415.846:631.415.1:631.435

Comparison of magnesium determination methods as influenced by soil properties

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Abstract

The current study was designed to investigate magnesium content in the soil. Magnesium was determined by the A-L (Egner-Riehm-Domingo), calcium chloride (Schachtschabel, 0.0125 M CaCl₂ 1:20), potassium chloride (1 M KCl 1:10), ammonium acetate (1 M NH₄OAc 1:10), Mehlich 3 methods and water soluble magnesium (1:5). The highest magnesium content in the soil was established using the A-L method, followed by calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods, while the lowest content was measured using water extract. The correlations between magnesium content determined by calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods were very strong – 0.96–0.99. The correlation between magnesium contents determined by these methods and A-L was obtained only in the case when the amount of magnesium determined by the latter method was below 500 mg kg⁻¹. The content of magnesium depended on soil texture and pH. The lowest magnesium content was measured in sand and sandy loam soils, while the highest content was recorded for clay loam. Soil pH exerted the greatest influence on the magnesium content determined by the A-L method.

Key words: magnesium, determination methods, soil texture, soil pH.

Introduction

Magnesium is one of the main nutrients in plant nutrition, therefore in many countries soils are tested for magnesium content to make sure whether it is expedient to apply magnesium fertilisation (Ristimaki, 2007, Roemheld, Kirkby, 2007). Having summarised the same soil samples analysed in 11 laboratories of 10 East and Central European countries it was established that using different methods, there were identified differences between the obtained results and their assessment, which ultimately resulted in different magnesium fertilizer rates (Fotyma, Dobers, 2008). Each country has its own validated methods best-suited for its soils.

Calcium chloride extract (Schachtschabel method) is used for magnesium determination in Poland, Slovenia, Germany and Austria and the contents measured are evaluated taking into account soil texture. However, in some countries assessment and indicated magnesium contents slightly differ, e.g. in Poland in a medium heavy soil magnesium content below 30 mg kg⁻¹ is considered as very low,

31–50 – low, 51–70 – moderate, 71–90 – high, more than 90 mg kg⁻¹ – very high (Jadczyzyn, 2009).

The potassium chloride method is used in Hungary and the contents measured are assessed according to the soil texture. In loamy sand and sandy loam soils, when the available magnesium content is up to 60 mg kg⁻¹, it is considered to be low, 61–100 – moderate and more than 100 mg kg⁻¹ – high (Fotyma, Dobers, 2008). Potassium chloride extract is used for magnesium determination also in Russia, Belarus, Ukraine and the Balkan countries.

Calcium and potassium chloride extracts are usually used only for magnesium determination, and available phosphorus and potassium are measured by other methods. It is time-consuming and requires higher reagent and labour input; therefore it is rational using one extract for the determination of all these nutrients (Matejovic, Durackova, 1994). It would be best to have a universal method for determination of many nutrients in the soil; as a result numerous experiments are conducted in this

area (Michaelson, Ping, 1987; Loide, 2001 b; Wang et al., 2004). One of such methods is Mehlich 3 used in Czechia, Slovakia, Estonia (Fotyma, Dobers, 2008). Here, the measured magnesium content according to 5 groups of richness is grouped for light, moderately heavy and heavy soils, e.g. in Czechia, for moderately heavy soils gradation of available magnesium, 5 groups of richness in arable soil are as follows: <105 mg kg⁻¹, 106–160, 161–255, 256–330, >330 mg kg⁻¹. However, these contents are different in the stands of perennial grasses, orchards, vineyards and hops plantations (Budnakova, Čermak, 2009).

In Lithuania and Sweden, magnesium together with phosphorus and potassium in the soil is determined by the A-L (Egner-Riehm-Domingo), and in Latvia by D-L (Egner-Riehm) method (Vuorinen, Makitie, 1955; Fotyma, Dobers, 2008). In Lithuania, the content of magnesium determined in the soil is grouped: 1) at pH ≤6.0, <40, 41–80, 81–120, 121–160, >160 mg kg⁻¹, 2) at pH >6.0, <100, 101–150, 151–200, 201–300, >300 mg kg⁻¹. According to this, magnesium fertilisation is expedient only at its lowest content in this scale (Lietuvos dirvožemių..., 1998). In Sweden, it is considered that magnesium fertilisers are effective only when magnesium content in the soil is below 100 mg kg⁻¹; moreover, attention is paid to the magnesium to potassium ratio (Vuorinen, Makitie, 1955). Estonian research evidence has shown that A-L method does not reflect accurately magnesium content in the soil and in this case the Schachtschabel method is better suited, and in Estonia the soils low in magnesium account for as much as 52% (Loide, 2001 a). Usually the distribution of magnesium content in the soil determined by some other methods is too narrow or too wide and this is a problem when choosing magnesium determination method. Magnesium content determined by the A-L and D-L methods is three and more times as high as that determined by Schachtschabel method, and the indicators obtained by these two methods differ little (Loide, 2001 b).

When soil is assessed according to FAO classification, soil base saturation is determined, at the same time sum of exchangeable cations obtained in ammonium acetate while determining calcium, magnesium, potassium and sodium (World reference base..., 2006). Since newly developed soil data bases present not only maps but also analysis of profiles, using these data it is possible to judge about magnesium content in the soil determined in ammonium acetate extract and at the same time about the necessity of magnesium fertilisation (Mažvila et al., 2006).

Research evidence suggests that magnesium content in the soil depends on soil texture, soil type, pH, and humus content; therefore these indicators already partly describe magnesium status in the soil (Lietuvos dirvožemių..., 1998; Lipinski, 2005). However, it is still not clear how the content of magnesium extracted by different methods depends on these indicators.

The objective of this work was to determine the content of magnesium in different soils extracted using the methods applied in Europe, to estimate the interrelationship and dependence on soil properties.

Research methods

The study was conducted during 2008–2010. A total of 122 soil samples were collected from 21 sites of Lithuania differing in soil typology, texture and pH. The soil samples were taken from 3 layers: 0–30, 30–60, 60–90 cm. The content of magnesium in the soil samples was established at the Agrochemical Research Centre of the Lithuanian Institute of Agriculture using the following techniques:

1. *Egner-Riehm-Domingo method* (abbreviated as A-L). The sample was extracted in the A-L buffer solution (1 M lactic acid, 3 M acetic acid and 1 M ammonium acetate, a solution was prepared from all the reagents, its pH was 3.7), soil to solvent ratio 1:20, stirred for 4 hours.

2. *Mehlich 3 method* (abbreviated as Me 3). The sample was extracted in Mehlich 3 solution (0.2 M acetic acid, 0.015 M ammonium fluoride, 0.013 M nitric acid, 0.25 M ammonium nitrate, 0.001 M ethylenediaminetetraacetic acid, a solution was prepared from all the reagents, its pH was 2.5), soil to solvent ratio 1:10, stirred for 5 minutes.

3. *Magnesium in CaCl₂ extract* (abbreviated as CaCl₂). The sample was extracted in 0.0125 M calcium chloride solution, soil to solvent ratio 1:20, stirred for 1 hour.

4. *Magnesium in KCl extract* (abbreviated as KCl). The sample was extracted in 1 M potassium chloride solution, soil to solvent ratio 1:10, stirred for 1 hour.

5. *Exchangeable magnesium* or magnesium determined in ammonium acetate extract (abbreviated as NH₄OAc). The sample was extracted in 1 M ammonium acetate solution (pH 7.0), soil to solvent ratio 1:10, stirred for 1 hour.

6. *Water soluble magnesium* (abbreviated as H₂O) was determined by extracting the sample in water, soil to solvent ratio 1:5, stirred for 1 hour.

Magnesium concentration in the samples extracted by various solvents was determined by the atomic absorption spectrometer AAnalyst 200 (“AAnalyst 200AA Spectrometer”).

The samples that had been analysed for magnesium content were grouped according to soil typology, texture and pH and were estimated using the following statistical indicators: arithmetic mean (\bar{x}), quadratic deviation (S), median (M_e) coefficient of variation (V), maximal (max) and minimal (min) values. The texture of the samples tested was divided into 4 groups: 1) sand, loamy sand, 2) sandy loam, 3) loam, 4) clay loam. The soil typology was divided according to Lithuania-specific and prevailing soils: 1) *Cambisols* and *Calc(ar)ic Luvisol*, 2) *Eutric* and *Gleyic Albeluvisols*, 3) *Haplic* and *Gleyic Luvisols*. The plough layer's pH_{KCl} was divided into 3 groups: <6.0, 6.0–7.0, >7.0. Using the correlation-regression method we established the relationship between magnesium contents established by different methods.

Results and discussion

Our experimental evidence showed that the highest magnesium contents in Lithuania's soils were established using the A-L method, much lower contents were measured by the other methods used, and the lowest contents were determined in water

extract (Table 1). The differences in magnesium content in various soil layers determined by calcium chloride, potassium chloride, ammonium acetate, and Mehlich 3 methods were negligible. Irrespective of the sampling depth, the arithmetic mean of magnesium content established by the four methods varied within 187–292 mg kg⁻¹ range. However, using the A-L technique, according to sampling depth the arithmetical means were obtained as follows: 0–30 cm – 655 mg kg⁻¹, 30–60 cm – 1220 mg kg⁻¹, 60–90 cm – 2427 mg kg⁻¹.

In water extract, the minimal and maximal values of magnesium content were 9 and 96 mg kg⁻¹. This suggests that in water extract only readily soluble salts were dissolved, such as magnesium nitrate, magnesium chloride, magnesium hydroxide, magnesium sulphate, whose contents are generally low in the soil. Using the A-L method we dissolved not only the above mentioned salts but also magnesium phosphates and part of magnesium carbonate, which occurs at high contents in calcareous soils, especially in deeper layers. Compared with the water extract, magnesium content, established by the A-L method, increased by as many as 25–70 times. In the soil analysed by other methods only a small part magnesium carbonate was dissolved, and compared with the water extract, magnesium content was 7–9 times higher.

Table 1. Magnesium contents in the soil determined by different methods

Soil layer cm, number of samples	Indicators	Mg content mg kg ⁻¹					
		A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3	H ₂ O
0–30 n = 41	\bar{x}	655	187	188	208	226	26
	S	806	119	129	148	158	12
	M_e	434	173	168	187	196	24
	V	123	64	69	71	70	48
	min	96	64	54	57	63	9
	max	4210	582	639	733	752	75
30–60 n = 41	\bar{x}	1220	223	249	266	292	32
	S	1671	166	218	228	246	19
	M_e	426	193	187	198	217	25
	V	137	74	88	86	84	59
	min	98	47	43	43	46	10
	max	7704	718	908	961	1004	96
60–90 n = 40	\bar{x}	2427	243	258	279	319	34
	S	2589	157	204	205	243	17
	M_e	566	191	186	213	255	30
	V	107	65	79	73	76	51
	min	95	49	42	49	44	8
	max	7938	712	854	844	958	86

While estimating the distribution of magnesium content within the 0–30 cm soil layer, it was found that as many as 97.6% of all soil samples analysed in water extract contained up to 50 mg kg⁻¹, and only 2.4% of the samples had a slightly higher content, but did not exceed the 100 mg kg⁻¹ limit (Table 2). However, magnesium content determined by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods distributed as follows: 22–24.4% of the samples tested were within 51–100 mg kg⁻¹ range, 31.7–43.9% of the samples within 101–200 mg kg⁻¹ range, and 14.6–29.3%

of the samples within 201–300 mg kg⁻¹ range. When magnesium content exceeded 300 mg kg⁻¹, the distribution of samples according to the methods employed was as follows: 9.8% were extracted in calcium chloride, 12.2% in potassium chloride, and 17.0–17.1% by Mehlich 3 and ammonium acetate methods, i.e. the amount of samples tested had a slightly higher magnesium content when analysed using the latter two methods. Whereas using the A-L method, the samples with magnesium content exceeding 500 mg kg⁻¹ accounted for 43.9%.

Table 2. The distribution of samples according to magnesium content (%) within 0–30 cm soil layer as influenced by various determination methods

Mg content mg kg ⁻¹	Distribution %					
	A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3	H ₂ O
0–50	0.0	0.0	0.0	0.0	0.0	97.6
51–100	2.4	22.0	24.4	22.0	22.0	2.4
101–150	12.2	19.5	19.5	17.1	12.2	0.0
151–200	9.8	31.7	29.3	24.4	19.5	0.0
201–300	14.6	17.1	14.6	19.5	29.3	0.0
301–400	7.3	0.0	4.9	9.8	7.3	0.0
401–500	9.8	4.9	2.4	2.4	2.4	0.0
>500	43.9	4.9	4.9	4.9	7.3	0.0

Correlation were calculated to estimate the relationship between soil magnesium determination methods (Table 3). A very weak correlation was established between the A-L and other magnesium determination methods for the 0–30 cm soil layer. A moderately strong correlation was obtained between water soluble magnesium content and calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods, and a very strong correlation 0.97–0.99 was found while comparing the four methods.

For the 30–60 cm soil layer, the correlation between A-L and calcium chloride, potassium chloride, ammonium acetate methods was weak, however, slightly higher than that for the 0–30 cm layer. The correlation between the A-L and Mehlich 3 methods was moderately strong, and no correlation was found with the water soluble magnesium content. Like for this layer, the same regularities were established for the 60–90 cm layer; however, the correlation between the A-L and calcium chloride, potassium chloride, ammonium acetate, Mehlich 3 methods was even stronger than for the 0–30 and 30–60 cm layers.

Magnesium content's correlation when comparing the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods was very strong for all soil layers.

In order to get a deeper insight into the relationship between the A-L and other magnesium determination methods we divided results scale in two parts. The first one, when magnesium content in the soil is up to 500 mg kg⁻¹, the second one when the magnesium content is 500–8000 mg kg⁻¹, and for comparison we left the entire scale 0–8000 mg kg⁻¹ (Fig. 1). For calculations we used soil analyses results for all layers.

Our research findings indicated that when the content of magnesium established by the A-L method was up to 500 mg kg⁻¹, the relationship between it and calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods was strong, and when the magnesium content measured by the A-L method ranged from 500 mg kg⁻¹ to 8000 mg kg⁻¹ there was no relationship between them. If we use all the data for the determination of the strength of the relationship, we see a very weak relationship between the A-L and other magnesium

determination methods. Thus, we can estimate the data of magnesium content established by the A-L and calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 when it does not ex-

ceed 500 mg kg^{-1} , and according to the equation of regression the best relationship was obtained when magnesium content was up to 300 mg kg^{-1} .

Table 3. Correlation coefficient between magnesium content in various soil layers determined by different methods

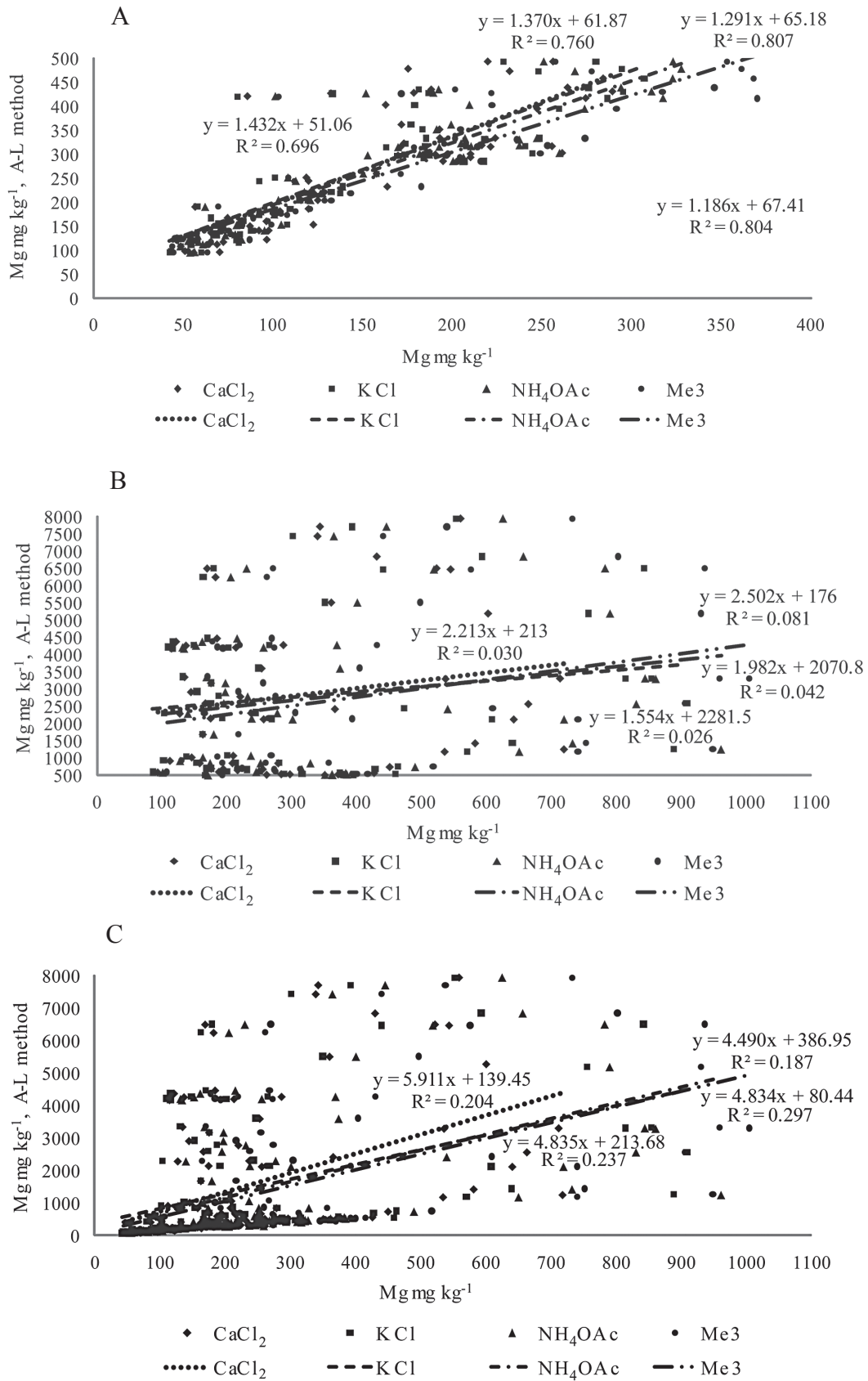
Methods	Methods				
	A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3
0–30 cm layer					
CaCl ₂	0.204				
KCl	0.217	0.982			
NH ₄ OAc	0.250	0.974	0.996		
Me 3	0.302	0.970	0.991	0.995	
H ₂ O	0.248	0.533	0.544	0.570	0.551
30–60 cm layer					
CaCl ₂	0.418				
KCl	0.394	0.972			
NH ₄ OAc	0.456	0.981	0.984		
Me 3	0.520	0.967	0.975	0.993	
H ₂ O	0.026	0.298	0.270	0.263	0.247
60–90 cm layer					
CaCl ₂	0.546				
KCl	0.509	0.956			
NH ₄ OAc	0.595	0.969	0.985		
Me 3	0.626	0.956	0.979	0.997	
H ₂ O	0.087	0.395	0.327	0.311	0.284

It is seen from the equations of regression that when the content of magnesium determined by the A-L method amounted to 100 mg kg^{-1} , this corresponded to about $65\text{--}70 \text{ mg kg}^{-1}$ established by calcium chloride, potassium chloride, ammonium acetate, Mehlich 3 methods. When the magnesium content measured by the A-L method amounted to 200 mg kg^{-1} , this corresponded to $95\text{--}110 \text{ mg kg}^{-1}$, when 300 mg kg^{-1} , this corresponded to $150\text{--}170 \text{ mg kg}^{-1}$.

The relationship of magnesium content in the soil between calcium chloride, potassium chloride, Mehlich 3 (x) with ammonium acetate (y) determination method (Fig. 2) was found to be very strong. This was determined when we estimated not only separate soil layers but also used the results for all layers for the calculations, which is presented in the Figure. Similar results were obtained when ana-

lysing the relationship of available magnesium content with the calcium chloride, potassium chloride, ammonium acetate (x) and Mehlich 3 (y) methods (Fig. 3). The highest magnesium content values were obtained when the soil was extracted by the Mehlich 3 method, followed by ammonium acetate, potassium chloride and calcium chloride methods.

Soil texture had a considerable effect on magnesium content; as a result, its content may have varied markedly (Table 4). In sand, loamy sand soils, at the 0–30 cm layer, the arithmetical mean of magnesium established by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods, varied very little – within the $94\text{--}102 \text{ mg kg}^{-1}$ range (Table 4). However, having estimated magnesium by the A-L method, the arithmetical mean value was 132 mg kg^{-1} , and minimal and maximal values were 96 and 175 mg kg^{-1} , respectively.



Note. The contents of magnesium established by the A-L method: A – 0–500 mg kg⁻¹, B – 500–8000 mg kg⁻¹, C – 0–8000 mg kg⁻¹.

Figure 1. The relationship between magnesium contents established by the A-L (y) and calcium chloride, potassium chloride, ammonium acetate, Mehlich 3 (x) methods

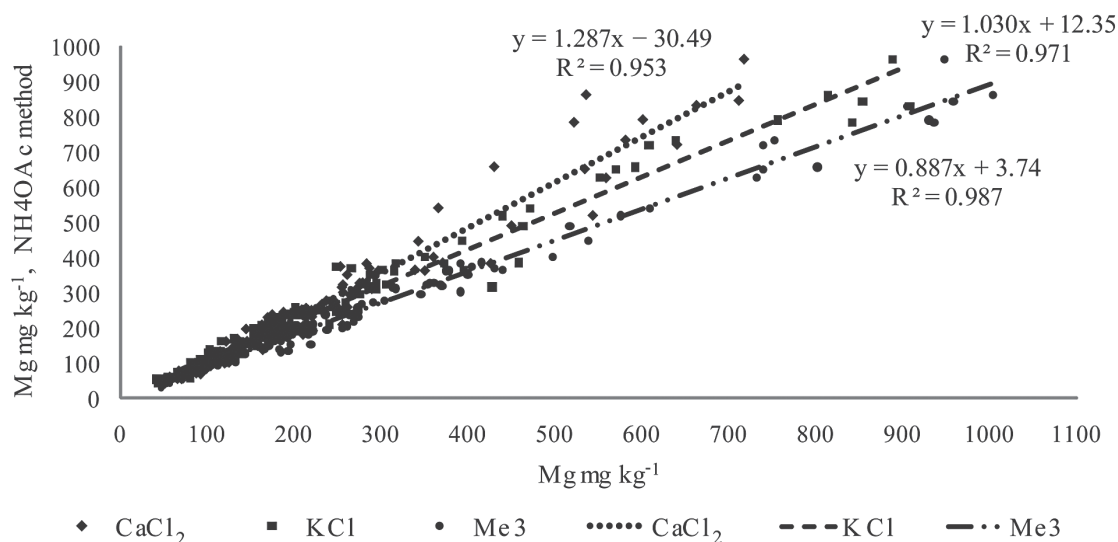


Figure 2. The relationship between ammonium acetate (y) and potassium chloride, calcium chloride and Mehlich 3 (x) magnesium determination methods

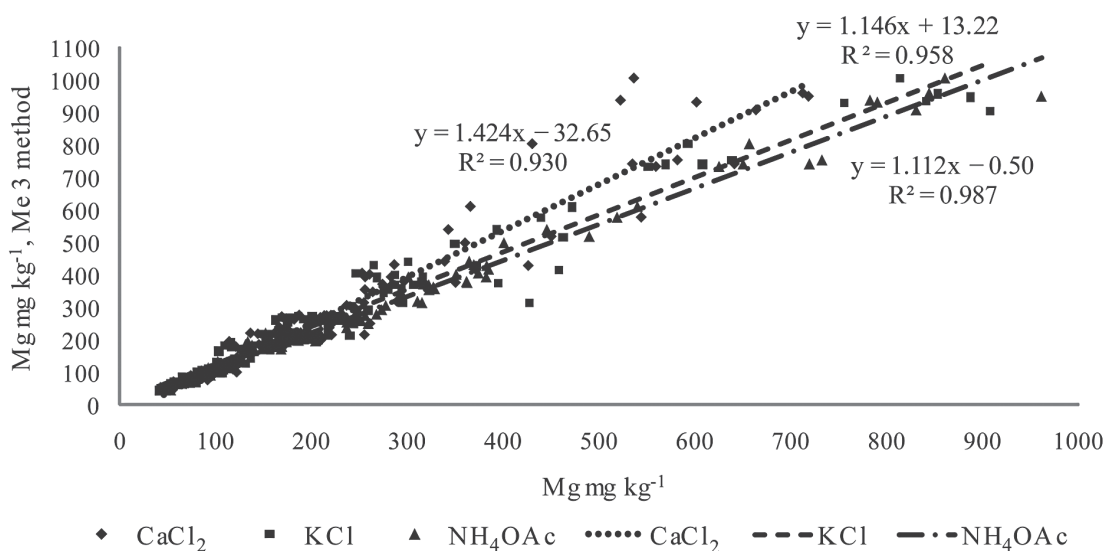


Figure 3. The relationship between Mehlich 3 (y) and potassium chloride, calcium chloride and ammonium acetate (x) magnesium determination methods

In sandy loam soils, at the same depth, the arithmetic mean of magnesium content established by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods fluctuated within the 145–176 mg kg⁻¹ range, and using the A-L method – 329 mg kg⁻¹, i.e. was nearly twice as high.

In loam soils, the arithmetic mean of magnesium content established by the A-L method was 438 mg kg⁻¹, and using the other test methods, except for the water extract, it was 156–188 mg kg⁻¹. In clay loam soils, the arithmetic means were 811 and 274–359 mg kg⁻¹, respectively. This suggests that heavier-textured soils had markedly higher contents of magnesium. However, if the contents of magne-

sium established by calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods in heavy loam soils was 2.5–3 times higher than those established in sandy soils, and no significant differences were established between the methods, the differences in magnesium contents established by the A-L method were 6 times higher due to the soil texture.

In deeper soil layers, like in the 0–30 cm layer, in heavier-textured soils, the content of magnesium increased. However, if the arithmetic mean of magnesium content established by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods was similar to that estab-

lished in the 0–30 cm layer and the highest contents of magnesium 250–530 mg kg⁻¹ were obtained in clay loam soils, the arithmetic mean of magnesium content established by the A-L method in the 30–60 cm layer was 2033 mg kg⁻¹, and that in the 60–90 cm layer was 3980 mg kg⁻¹.

The content of water soluble magnesium in the soil was very low. Its content was also affected by the soil texture: in sandy soil the arithmetic mean was 21 mg kg⁻¹, in heavy loam soils 31 mg kg⁻¹. The medians made up 15 and 28 mg kg⁻¹, respectively.

Table 4. The distribution of magnesium content determined by different methods within the 0–30 cm soil layer

Texture	Indicators	Mg content mg kg ⁻¹					
		A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3	H ₂ O
Sand, loamy sand n = 6	\bar{x}	132	98	94	96	102	21
	<i>S</i>	26	37	34	47	52	13
	<i>M_e</i>	133	85	85	86	83	15
	<i>V</i>	20	38	36	48	51	58
	<i>min</i>	96	67	60	57	63	9
	<i>max</i>	175	176	168	195	215	40
Sandy loam n = 13	\bar{x}	329	158	145	157	176	21
	<i>S</i>	185	90	80	82	93	7
	<i>M_e</i>	293	123	121	132	185	22
	<i>V</i>	56	57	55	52	53	33
	<i>min</i>	112	69	54	61	64	9
	<i>max</i>	691	426	373	383	427	31
Loam n = 9	\bar{x}	438	163	156	171	188	28
	<i>S</i>	255	60	61	78	80	18
	<i>M_e</i>	322	164	153	175	193	22
	<i>V</i>	58	37	39	45	42	64
	<i>min</i>	136	66	68	57	67	12
	<i>max</i>	853	279	280	329	356	75
Clay loam n = 13	\bar{x}	811	274	297	335	359	31
	<i>S</i>	513	145	157	178	190	9
	<i>M_e</i>	652	217	231	252	273	28
	<i>V</i>	63	53	53	53	53	28
	<i>min</i>	204	116	119	121	129	23
	<i>max</i>	2150	582	639	733	752	54

Soil types did not have any consistent effect on the content of magnesium established by different methods (Table 5). In various soil types, the arithmetic mean of magnesium content determined by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods varied within the 187–233 mg kg⁻¹ range, and quadratic deviation was as high as 119–188 mg kg⁻¹. The magnesium content established by the A-L method was 3 times as high as that determined by the other methods, and in various soils the arithmetic mean of magnesium content fluctuated within the 495–

688 mg kg⁻¹ range, when quadratic deviation was as high as 485–847 mg kg⁻¹. The arithmetic mean of available magnesium content in water extract in various soil systematics units was 24–26 mg kg⁻¹, and minimal and maximal value was 9 mg kg⁻¹ and 75 mg kg⁻¹, respectively.

Soil pH affected magnesium content (Table 6); however, the dependence of magnesium content established in different extracts on soil pH was diverse. Soil pH had the greatest effect on the magnesium content established in the A-L extract. When the 0–30 cm soil layer's pH was below 6.0,

the arithmetic mean of magnesium was 173 mg kg⁻¹, when pH was 6.0–7.0 – 573 mg kg⁻¹, and at a pH above 7.0 the content of magnesium was as high as 2639 mg kg⁻¹. In the 30–60 cm layer, the contents of magnesium varied even more – 267, 1133 and 3262 mg kg⁻¹, respectively. Such high content of magnesium in not acid soils resulted from magnesium carbonate content, which was readily dis-

solved by the A-L extract. Carbonate content was low only in the 0–30 cm layer, when pH was below 6.0. However, the maximal magnesium content obtained here made up 299 mg kg⁻¹ and was only by approximately 1.5 times higher compared with that obtained using calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods, where its maximal contents were 184–210 mg kg⁻¹.

Table 5. The magnesium content determined by different methods in the 0–30 cm layer of various soils

Number of soil samples	Indicators	Mg content mg kg ⁻¹					
		A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3	H ₂ O
<i>Cambisols and Calc(ar)ic Luvisol</i> n = 13	\bar{x}	688	192	194	214	233	25
	<i>S</i>	847	123	134	152	163	9
	<i>M_e</i>	456	174	174	190	196	25
	<i>V</i>	123	64	69	71	70	38
	<i>min</i>	318	86	80	102	103	13
	<i>max</i>	2150	582	639	733	752	54
<i>Eutric and Gleyic Albeluvisols</i> n = 8	\bar{x}	495	191	188	206	223	24
	<i>S</i>	485	145	155	175	188	11
	<i>M_e</i>	232	158	139	139	185	26
	<i>V</i>	98	76	82	85	84	45
	<i>min</i>	112	69	54	61	64	9
	<i>max</i>	585	210	184	206	204	31
<i>Haplic and Gleyic Luvisols</i> n = 13	\bar{x}	595	187	188	208	226	26
	<i>S</i>	718	119	129	148	158	12
	<i>M_e</i>	420	173	168	187	196	24
	<i>V</i>	121	64	69	71	70	48
	<i>min</i>	136	66	68	57	67	12
	<i>max</i>	853	279	280	329	356	75

The arithmetic mean of magnesium content determined by the calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods was lower when soil pH was below 6.0 and in the 0–30 cm layer made up 112, 102, 102, 111 mg kg⁻¹, respectively, and in the 30–60 cm layer – 158, 170, 164 and 175 mg kg⁻¹, respectively. The arithmetic mean of magnesium content when using these extracts doubled at a pH of 6.0–7.0. However, at a pH higher than 7.0, the mean of magnesium at the 30–60 cm layer was slightly lower, at the 0–30 cm layer a bigger reduction occurred and this might have been influenced by a small number of samples. In water extract, the lowest content of magnesium was only in the 0–30 cm layer at a pH below 6.0.

When soil was extracted by calcium chloride, potassium chloride and ammonium acetate solutions, the cations of their salts ousted magnesium cations from the soil, therefore we determined the sum of this and water soluble magnesium. When the soil had been extracted with a very acid A-L solution, containing ammonium acetate, for 4 hours, not only magnesium cations absorbed by the soil moved into the solution but also some part of minerals dissolved, especially magnesium carbonate, whose content was high in *Cambisols and Calc(ar)ic Luvisol*. The soil was extracted with an acid Mehlich 3 solution only for 5 minutes, therefore magnesium absorbed by the soil transited into it, and the time was too short for magnesium content present in minerals to dissolve.

Table 6. The effect of soil pH_{KCl} on the content of magnesium determined by different methods

pH _{KCl} value, number of samples	Indicators	Mg content mg kg ⁻¹					
		A-L	CaCl ₂	KCl	NH ₄ OAc	Me 3	H ₂ O
0–30 cm layer							
<6.0 n = 13	\bar{x}	173	112	102	102	111	18
	<i>S</i>	66	49	41	49	52	9
	<i>M_e</i>	153	98	88	92	97	17
	<i>V</i>	38	44	40	48	47	47
	<i>min</i>	112	66	54	57	63	9
	<i>max</i>	299	210	184	206	204	37
	6.0–7.0 n = 23	\bar{x}	573	235	242	270	290
<i>S</i>		303	138	149	168	181	14
<i>M_e</i>		504	193	186	207	223	26
<i>V</i>		53	59	62	62	62	46
<i>min</i>		167	75	65	75	89	13
<i>max</i>		1430	582	639	733	752	75
>7.0 n = 4		\bar{x}	2639	152	154	183	222
	<i>S</i>	1368	30	38	46	43	3
	<i>M_e</i>	2662	160	156	181	220	26
	<i>V</i>	52	20	24	25	20	10
	<i>min</i>	1021	113	109	132	185	23
	<i>max</i>	4210	176	193	239	264	28
	30–60 cm layer						
<6.0 n = 18	\bar{x}	267	158	170	164	175	34
	<i>S</i>	160	91	119	106	111	25
	<i>M_e</i>	202	121	123	115	132	28
	<i>V</i>	60	57	70	65	64	72
	<i>min</i>	98	47	43	43	46	10
	<i>max</i>	679	351	428	363	375	96
	6.0–7.0 n = 14	\bar{x}	1133	299	338	371	393
<i>S</i>		1102	219	278	286	293	15
<i>M_e</i>		504	221	224	253	273	30
<i>V</i>		97	73	82	77	75	47
<i>min</i>		130	54	58	58	67	16
<i>max</i>		3598	718	908	961	948	61
>7.0 n = 9		\bar{x}	3262	236	270	307	368
	<i>S</i>	2277	149	232	240	283	12
	<i>M_e</i>	2914	145	154	198	217	24
	<i>V</i>	70	63	86	78	77	44
	<i>min</i>	426	113	102	128	130	14
	<i>max</i>	7704	536	814	861	1004	55

Conclusions

1. The contents of magnesium in the soil determined by various methods differed. The highest magnesium content was established by the A-L method, where 24.4% of all samples tested contained up to 200 mg kg⁻¹ of magnesium, 31.7% of the samples contained 201–500 mg kg⁻¹, and 43.9% of the samples contained more than 500 mg kg⁻¹. In the 0–30, 30–60 and 60–90 cm soil layers the maximal values of magnesium amounted to 4210, 7704 and 7938 mg kg⁻¹, respectively.

2. When magnesium content was measured by the calcium chloride, potassium chloride, ammonium acetate, and Mehlich 3 methods, the samples containing up to 500 mg kg⁻¹ of magnesium accounted for 95.1–97.6%, and the arithmetic means for the 0–30 cm layer were 187, 188, 208 and 226 mg kg⁻¹. The least magnesium contents were measured in water extract, where its content ranged from 8 to 96 mg kg⁻¹.

3. The correlation established between magnesium content determined by calcium chloride, potassium chloride, ammonium acetate, and Mehlich 3 methods were very strong – 0.96–0.99. The correlation between these methods and A-L was obtained only when the magnesium content established by the latter method did not reach 500 mg kg⁻¹. There was not found any correlation between the water soluble magnesium content and that determined by the A-L method; however, the relationship of water soluble magnesium content with the other methods investigated was moderate for the 0–30 cm soil layer, and weak for the 30–60 and 60–90 cm layers.

4. The content of magnesium depended on soil texture and pH. The lowest contents of magnesium was established in sand and sand loam soils, while the highest contents were measured in clay loam, where the difference of arithmetic means between these soil textures using the A-L method was 6.1 times, calcium chloride, potassium chloride, ammonium acetate and Mehlich 3 methods – 2.8–3.7 times, and using the water extract the difference was 1.5 times. Soil pH had the greatest influence on the magnesium content established by the A-L method. At a lower pH, i.e. 6.0 in the 0–30 cm soil layer, arithmetic mean of magnesium was 173 mg kg⁻¹, at a pH of 6.0–7.0 – 573 mg kg⁻¹, at a pH >7.0 – 2636 mg kg⁻¹.

Received 30 08 2010

Accepted 17 09 2010

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ISSN 1392-3196

Žemdirbystė=Agriculture, t. 97, Nr. 3 (2010), p. 105–116

UDK 631.415.846:631.415.1:631.435

Magnio nustatymo metodų palyginimas priklausomai nuo dirvožemio savybių

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Santrauka

Tirtas įvairiais metodais nustatytas magnio kiekis dirvožemyje. Magnis nustatytas A-L (Egner-Riehm-Domingo), kalcio chlorido (Schachtschabel, 0,0125 M CaCl_2 1:20), kalio chlorido (1 M KCl 1:10), amonio acetato (mainų magnis) (1 M NH_4OAc 1:10), Mehlich 3 metodais ir vandenyje (1:5). Daugiausia magnio dirvožemyje nustatyta taikant A-L metodą, mažiau – kalcio chlorido, kalio chlorido, amonio acetato ir Mehlich 3 ištraukose, o mažiausiai – vandenyje. Koreliacinis ryšys tarp magnio kiekio, nustatyto kalcio chlorido, kalio chlorido, amonio acetato ir Mehlich 3 metodais, gautas labai stiprus – 0,96–0,99. Koreliacinis ryšys tarp šių metodų ir A-L gautas tik tuomet, kai pastaruoju metodu nustatytas magnio kiekis nesiekė 500 mg kg^{-1} . Magnio kiekis priklauso nuo dirvožemio granulometrinės sudėties ir pH. Mažiausiai magnio nustatyta smėlio ir priesmėlio, daugiausia – sunkaus priemolio dirvožemiuose. Dirvožemio pH labiausiai veikė A-L metodu nustatytą magnio kiekį.

Reikšminiai žodžiai: dirvožemio magnis, magnio nustatymo dirvožemyje metodai, granulometrinė sudėtis, dirvožemio pH.